

# Scaling Cooperative Diversity to Large Networks

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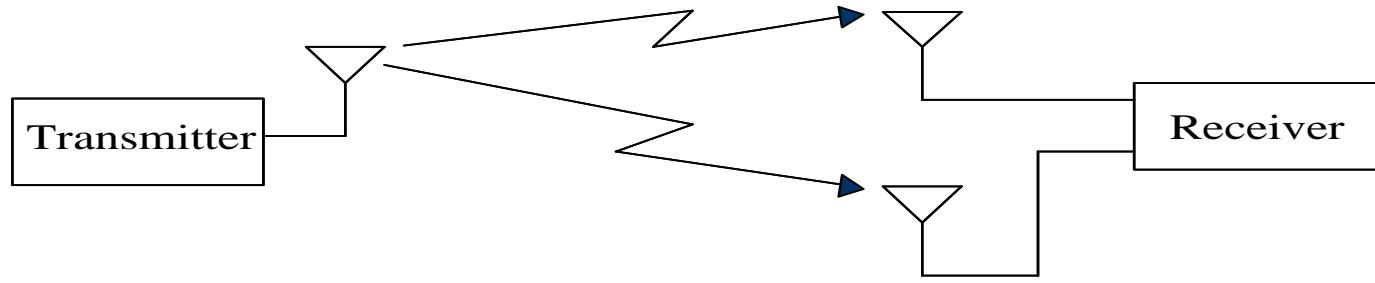
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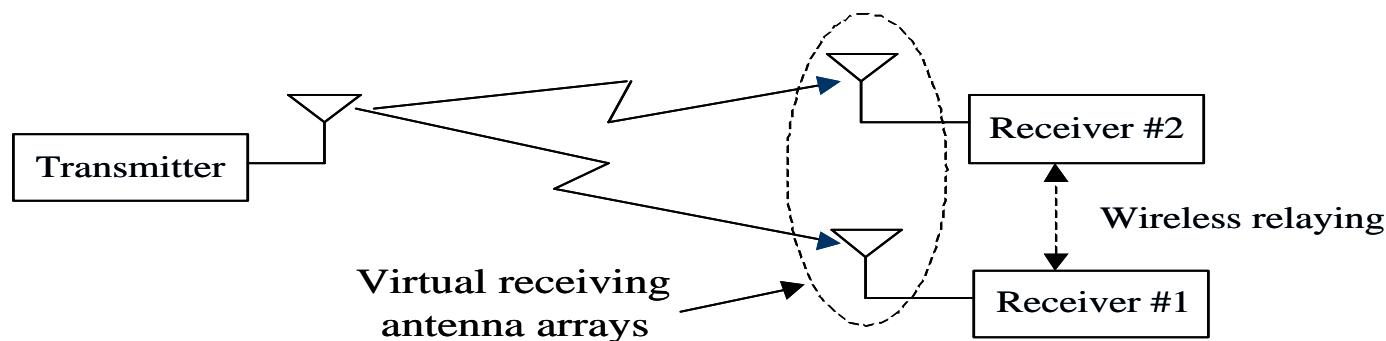
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# Cooperative Diversity via Distributed Array (Laneman)

- Spatial diversity through antenna array.

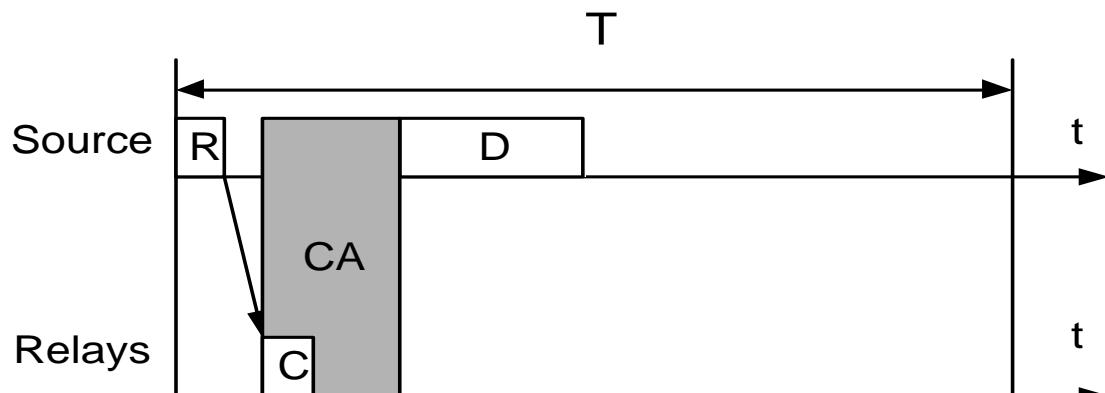


- Cooperative diversity through virtual antenna array.

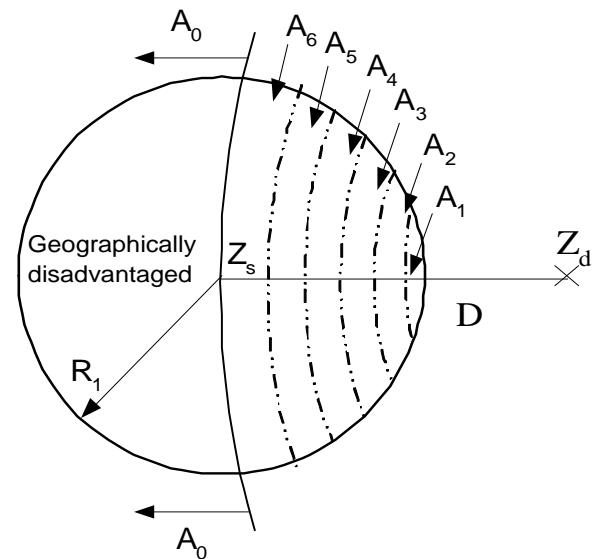


# Geographic Random Forwarding (Zorzi & Rao)

- The GeRaF protocol.
  - Source node broadcasts its message without picking the relaying node a priori.
  - A contention scheme assures that the node closest to the destination acts as relay.
  - Especially suitable for sensor networks with nodes that cycle in and out of sleep states.



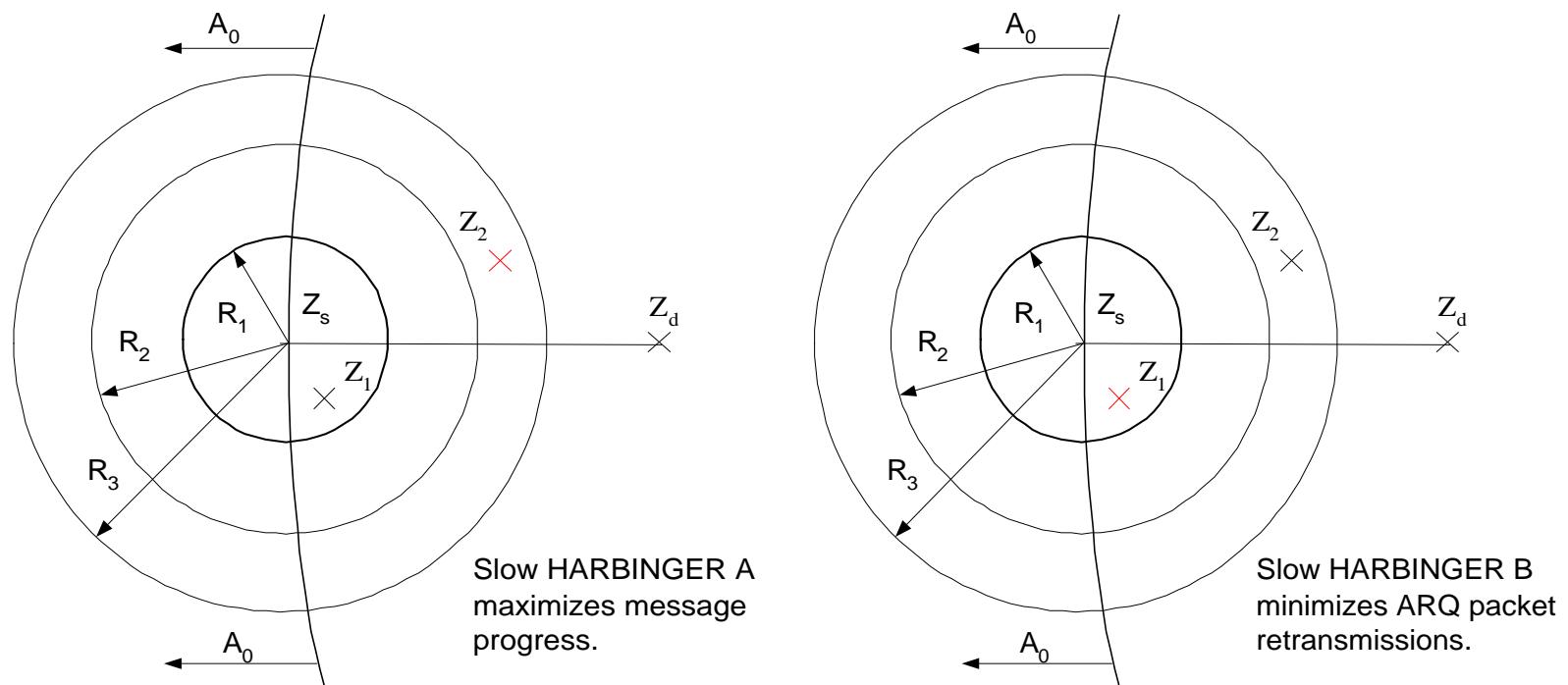
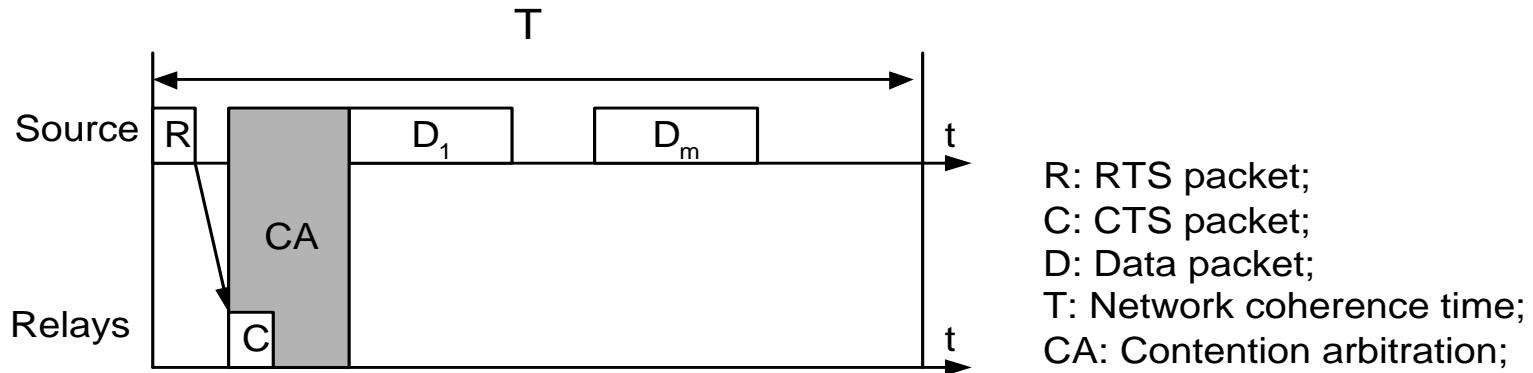
R: RTS packet; C: CTS packet;  
 D: Data packet; CA: Contention arbitration;  
 T: network coherence time (time that topology is fixed);



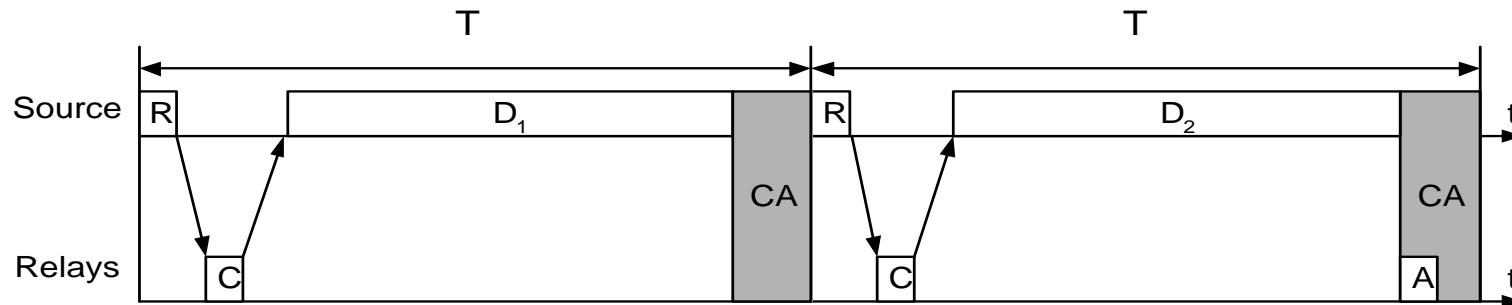
# Hybrid ARq Based INtra-cluster GGeographic Relaying

- Drawback of GeRaF.
  - Excessive message delay in low (active node) density networks.
- The HARBINGER Protocol.
  - Preserve protocol structure and priority zone-splitting mechanism in GeRaF.
  - Utilize hybrid-ARQ to expand coverage radius to  $R_M$  ( $M$  is rate constraint).
  - Cross-layer protocol combines cooperative diversity, hybrid-ARQ, and routing.
- Type II hybrid-ARQ retransmission.
  - Through puncturing, different fraction of a rate  $r$  mother codeword is transmitted per time slot  $s_m = \{s_1, s_2, \dots, s_M\}$  where each time slot is of unit duration.
  - Assuming capacity approaching codes and maximum likelihood detection.
  - The accumulated mutual information at  $Z_j$ :  $I_j[m] = \sum_{i=1}^m \frac{1}{2M} \log_2(1 + \gamma_j[i])$ .
  - Once  $I_j[m] \geq r$ ,  $Z_j \in \mathcal{D}(s_m + 1)$  and  $Z_j$  may act as relay.
  - Once a relay forwards the message, all nodes flush their memory of previous transmissions.

## Slow HARBINGER: $T > 1$



# Fast HARBINGER: $T = 1$



R: RTS packet; C: CTS packet; A: ACK packet; D: Data packet;  
 CA: Contention arbitration; T: Network coherence time;

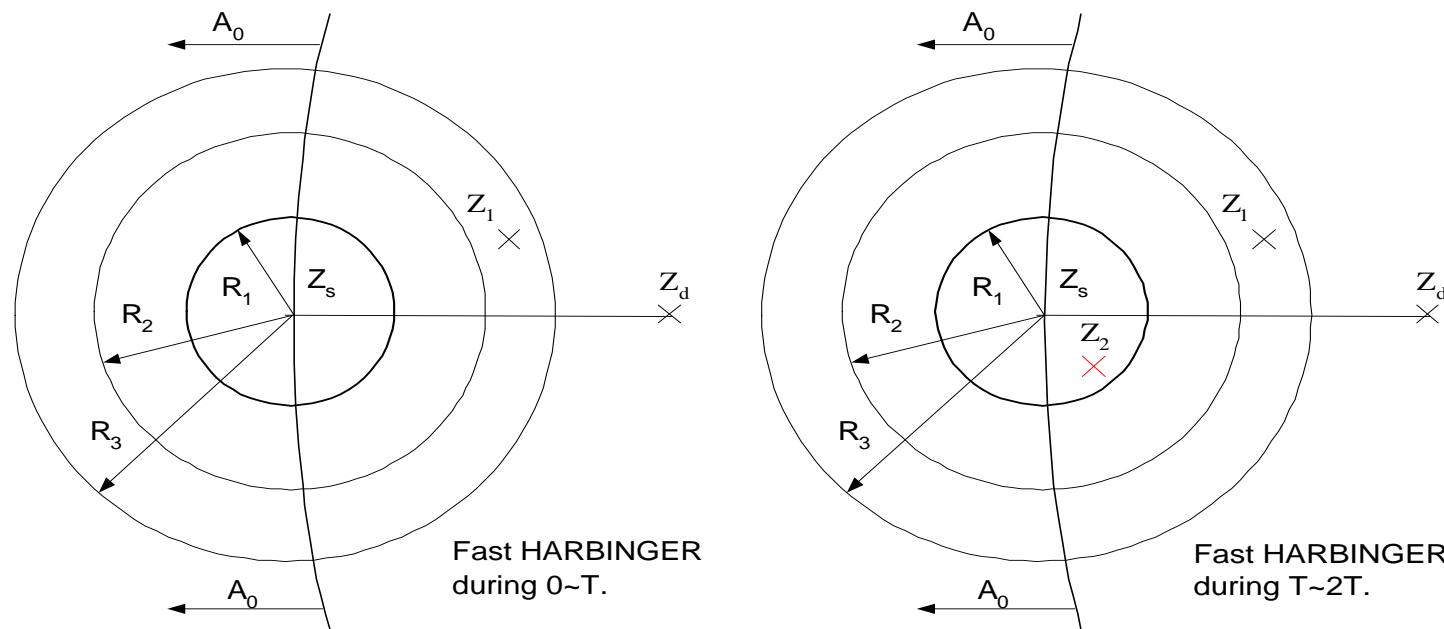


Figure 1: The message delay in different versions of HARBINGER under rate constraint  $M = 2$  and source-destination separation  $D = 10$ . Transmit power is normalized to  $R_1 = 1$  and path-loss coefficient  $\mu = 3$ .

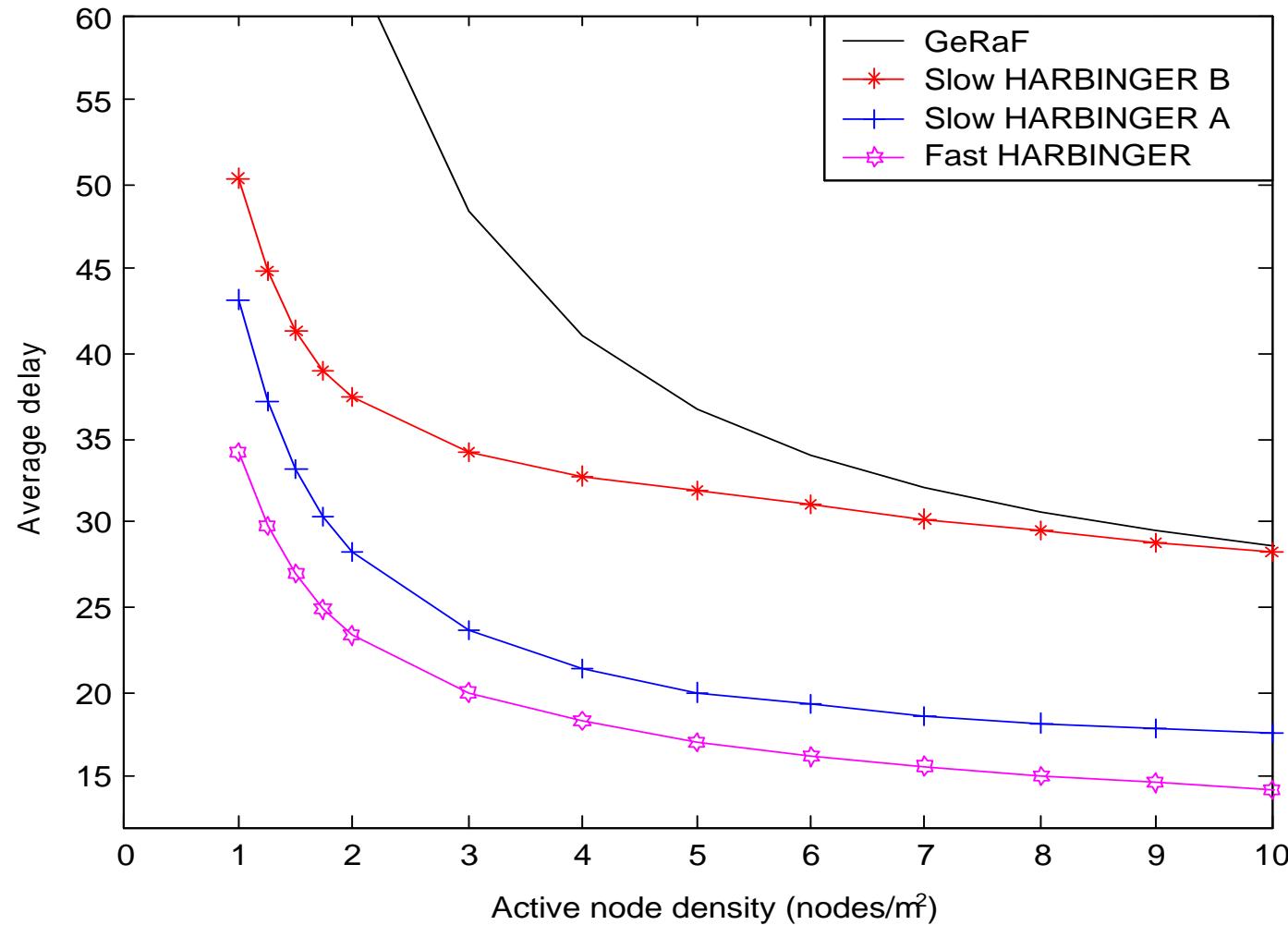
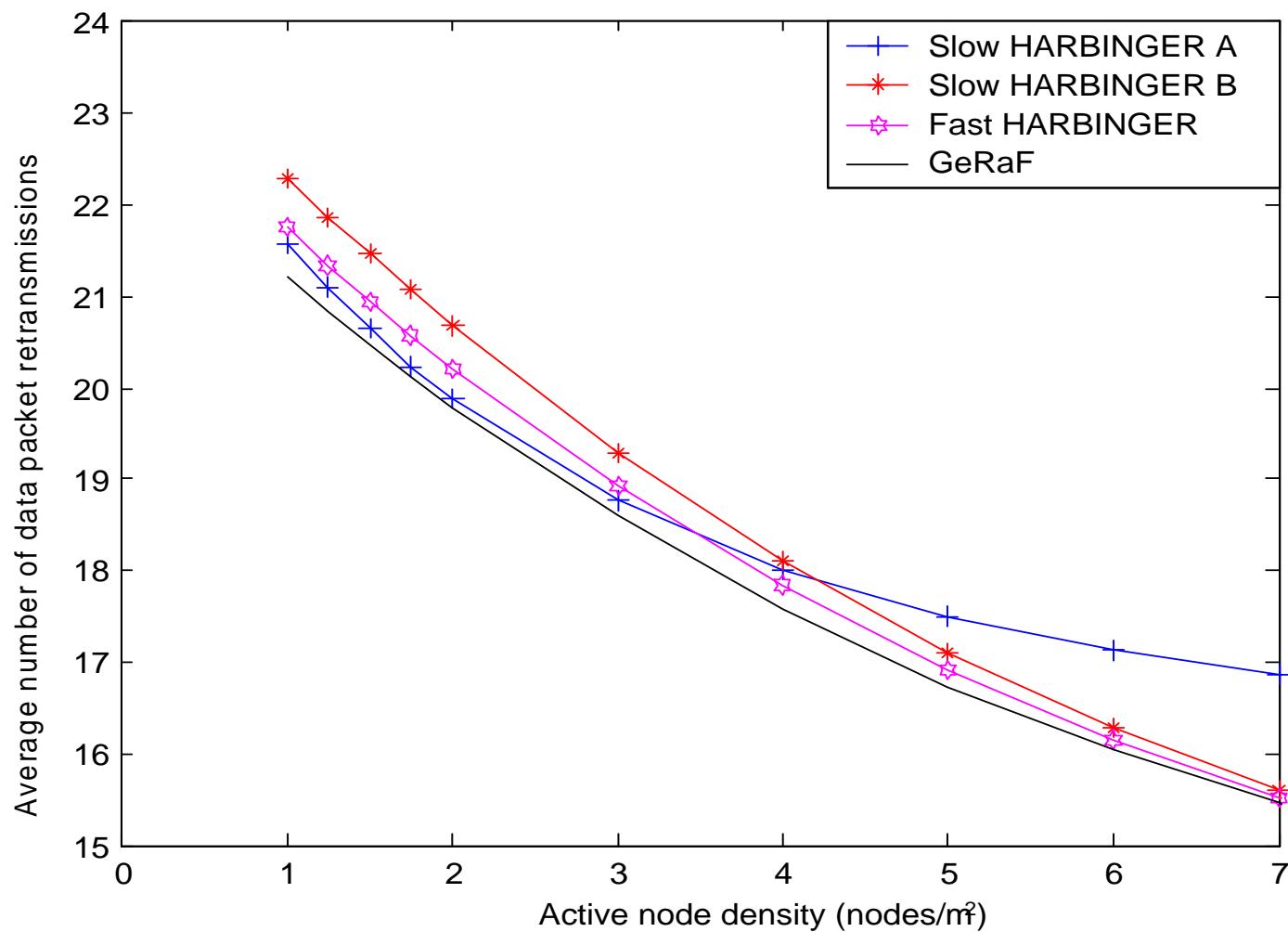


Figure 2: The energy efficiency of different versions of HARBINGER under rate constraints  $M = 2$  and source-destination separation  $D = 10$ .



# Conclusions

- HARBINGER is a cross-layer protocol combining cooperative diversity, hybrid-ARQ, and routing.
- Comparison of HARBINGER and GeRaF.
  - HARBINGER is a generalization of GeRaF.
  - GeRaF is HARBINGER with  $M = 1$ .
  - HARBINGER has shorter delay than GeRaF.
  - HARBINGER requires more transmit energy.
  - HARBINGER allows low sleep duty cycles.
- Different versions of HARBINGER are developed for different network applications.
  - Slow HARBINGER A maximizes message progress, thus minimizes delay.
  - Slow HARBINGER B minimizes data packet retransmission, thus is more energy efficient than Slow HARBINGER A.
  - Fast HARBINGER synchronizes data packet retransmission with device sleeping cycles, thus also benefiting from time diversity.
- Without memory flushing HARBINGER should have much better performance but requires more complicated analysis.

# Publications

1. B. Zhao and M.C. Valenti, "A block-fading perspective on energy efficient random access relay networks," to appear in *IEEE Journal on Selected Areas in Commun. (Special Issue on Wireless Ad Hoc Networks)*.
2. B. Zhao and M.C. Valenti, "Distributed turbo coded diversity for the relay channel," *IEE Electronics Letters*, vol. 39, no. 10, pp. 786-787, May 15, 2003.
3. B. Zhao, R. Iyer Seshadri, and M.C. Valenti, "Geographic random forwarding with hybrid-ARQ for ad hoc networks with rapid sleep cycles," to appear in *Proc. IEEE GLOBECOM*, (Dallas, TX), Dec. 2004.
4. M.C. Valenti and B. Zhao, "Hybrid-ARQ based intra-cluster geographic relaying," to appear in *Proc. IEEE MILCOM*, (Monterey, CA), Nov. 2004.
5. S. Wei, D. Goeckel, and M. Valenti, "Asynchronous cooperative diversity," in *Proc. Conf. on Info. Sci. and Sys. (CISS)*, (Princeton, NJ), Mar. 2004.
6. B. Zhao and M.C. Valenti, "Some new adaptive protocols for the wireless relay channel," in *Proc. Allerton Conf. on Commun., Control, and Comp.*, (Monticello, IL), Oct. 2003.
7. M.C. Valenti and B. Zhao, "Distributed turbo codes: Towards the capacity of the relay channel," in *Proc. IEEE Vehicular Tech. Conf. (VTC)*, (Orlando, FL), Oct. 2003.
8. B. Zhao and M.C. Valenti, "Cooperative diversity using distributed turbo codes," in *Proc. Virginia Tech Symp. on Wireless Personal Commun.*, (Blacksburg, VA), June 2003.